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Short Communication

An update of the distribution of *Boeckella gracilis* (Daday, 1902) (Crustacea, Copepoda) in the Araucania region (38ºS), Chile, and a null model for understanding its species associations in its habitat

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ABSTRACT. The crustacean zooplankton of Chilean inland waters are characterized by abundant calanoid copepods, mainly from the genus *Boeckella*. The present study aims to update the distribution of *Boeckella gracilis* in the inland waters of the Araucania region (38-39ºS) and to use null model analysis to understand the *B. gracilis* species associations. In the literature for Chile, this species is reported to be found in one northern lake and in three lakes of northern Patagonia. These findings are complemented by reports of this species for coastal and mountain ponds and mountain lakes of the Araucania region. These results agree with descriptions of this species for South American inland waters. The results of the null model analysis reveal factors regulating the species associations, whether comparing all the inhabitats or the guild structure, although some simulations show the opposite situation due to the presence of repeated species at many sites.

Keywords: *Boeckella*, zooplankton, null model, Patagonia, Chile.

Actualización de la distribución de *Boeckella gracilis* (Daday, 1902) (Crustacea, Copepoda) en la region de la Araucanía (38ºS), Chile, y un modelo nulo para comprender sus asociaciones específicas en su hábitat

RESUMEN. Los crustáceos zooplanctónicos en aguas continentales chilenas están caracterizados por la abundancia de copépodos calanoideos, principalmente del género *Boeckella*. El objetivo del presente trabajo es actualizar la distribución de esta especie en aguas continentales de la región de la Araucanía (38-39ºS), y el uso de modelos nulos para comprender sus especies asociadas. Las descripciones de la literatura indican que en Chile esta especie está en un lago del norte, y tres lagos en el norte de la Patagonia. Estos resultados están complementados con reportes de esta especie en pozas costeras, pozas y lagos de montaña en la región de la Araucanía. Estos resultados concuerdan con las descripciones de esta especie para aguas continentales Sudamericanas. Los resultados del análisis de modelos nulos revelan que las asociaciones de especies tuvieron factores reguladores, ya sea comparando todos los habitantes y como estructura de gremios, aunque en algunas simulaciones se observó una situación opuesta, esto se debió a la presencia de especies repetidas en muchos sitios.

Palabras clave: *Boeckella*, zooplancton, modelos nulos, Patagonia, Chile.

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Calanoid copepods are dominant in the zooplankton assemblages of Chilean inland waters due mainly to the oligotrophy of their habitats (Soto & Zúñiga, 1991; De los Ríos & Soto, 2006) but also to their high conductivity (Soto & De los Ríos, 2006). The calanoid copepods are represented by the genera *Boeckella*, *Parabroteas*, and *Tumeodiaptomus* (Soto & Zúñiga, 1991). *Boeckella* is the most widespread, with 11 species living throughout continental Chile (Bayly, 1992; Menu-Marque *et al.*, 2000). One of the species reported for Chilean inland waters is *B. gracilis* (Daday, 1902). Widespread in South American inland waters, this species is found mainly in tropical zones and from the eastern Andes Mountains to the Argentinean Patagonia (43ºS; Menu-Marque *et al.*, 2000; Trochine *et al.*, 2008). For Chilean inland waters, *B. gracilis* was reported at five sites: one in northern Chile (18ºS) and the other four in northern Patagonia (38-41ºS). Unfortunately, there are no more reports of this species in Chilean inland waters. Nevertheless, unpublished data offer preliminary descriptions of the presence of this species in mountain lakes at 38-39ºS. Although no additional reports of this species have been made (Villalobos, 2006), its presence in northern Patagonian inland waters has been proposed. The present study aims to update the distribution of *B. gracilis* and its associated species and to interpret its species associations using null model analysis.

The present review of the geographical distribution of *B. gracilis* includes the literature describing *B. gracilis* for Chilean inland waters (Brehm, 1937; Loefler, 1961; Zúñiga & Domínguez, 1978; Andrew *et al.*, 1989) as well as recent findings (De los Ríos *et al.*, 2007; De los Ríos & Roa, 2010) and field studies of the inland waters of the Araucania region, southern Chile (38ºS). These studies were done between September 2008 and September 2009 in two settings. The first, Marimenuco, is a mountain plain that has the following macrophyte species: *Isoetes savatieri*, *Anagallis alternifolia*, *Aster vahlii*, *Gratiola peruviana*, *Carex decidua*, *C. macloviana*, *Juncus imbricatus*, and *J. procerus*; and the second, Puaucho, is a coastal dune area with macrophyte species found in salt marshes: *Selliera radicans*, *Distichlis spicata*, *Juncus articus*, *Scirpus americanus*, *S. olneyi*, and *Rumex cuneifolius*. The specimens were collected and fixed with absolute ethanol, then identified with specialized literature (Araya & Zúñiga, 1985; Reid, 1985; Bayly, 1992; González, 2003).

An absence-presence matrix was used for the species association analysis implemented to test the hypothesis that the reported species are not randomly associated. For this, we used the "C score" index (Stone & Roberts, 1990), which determines co-occurrence based on presence/absence (1/2) matrices for given zooplankton species in the sample. Following Gotelli (2000) and Tiho & Johens (2007), the presence/absence matrix was analysed as follows. (a) Fixed-fixed: In this algorithm, the row and the column sums of the original matrix are preserved. Thus, each random community contains the same number of species as the original community (fixed column), and each species occurs with the same frequency as in the original community (fixed row). This algorithm is not prone to type-I errors (falsely rejecting the null hypothesis) and has good power for detecting non-randomness (Gotelli, 2000, 2001; Tiho & Johens, 2006). (b) Fixed-equiprobable: In this simulation, the row sums are fixed, but the columns are treated as equiprobable. This null model treats all the samples (columns) as equally suitable for all species (Tiho & Johens, 2006; Gotelli, 2000). (c) Fixed-proportional: In this algorithm, the totals for species occurrence are maintained as in the original community, and the probability that a species will occur in a sample (= column) is proportional to the column total for that sample (Gotelli, 2000; Tiho & Johens, 2006; Tondoh, 2007). Ecosim software was used for all these analyses (Gotelli & Entsminger, 2009).

Our review of the geographical distribution showed that, prior to the recent field studies, *B. gracilis* had been reported in the literature at the following sites: Chungara Lake (18°15'S, 69°10'W) (Andrew *et al.*, 1989); Riñihue Lake (39°50'S, 72°19'W) (Zúñiga & Domínguez, 1978); Calbuco Lagoon (41°16'S, 72°32'W) (Löffler, 1961); and Mausa (41°27'S, 72°58'W) (Brehm, 1937). More recent literature and findings have revealed the presence of this species in Cañi Park at the ponds Del Risco, Negrita, Escondida, De los Patos, Negra, and Vaca Hundida (39º15'S, 79º42'W) as well as Los Pastos and Seca (39º15'S, 79º43'W) (De los Ríos & Roa, 2010). In Huerquehue National Park, *B. gracilis* was also found in Verde I Lake (39°10'S, 71°43'W), Los Patos Pond (39º10'S, 71º42'W) (De los Ríos *et al.*, 2007), and Tinquilco Lake (39°10'S, 71°43'W) (De los Ríos *et al.*, 2007). In Conguillío National Park, this species was observed in Verde II Lagoon (38°40'S, 71°37'W) (De los Ríos *et al.*, present study; collected in March 2007). Moreover, specimens have been reported from shallow pools in the coastal dunes of Puaucho Beach (38º57'S, 73º19'-73º20'W) (De los Ríos, *et al.*, present study, collected in September 2009) and the ponds of the Marimenuco mountain plain (38º40'S, 71º05'W) (De los Ríos *et al.*, present study, collected in September 2008).

These results revealed the existence of *B. gracilis* in small mountain lakes (e.g., Captren, Tinquilco, and Verde II), where it can coexist with cladocerans such as *Ceriodaphnia dubia* and *Neobosmina chilensis* (Table 1). *B. gracilis* can also inhabit permanent shallow mountain ponds (e.g., Cañi Park), coexisting with species such as *Daphnia pulex*, *C. dubia*, *Diaphanosoma chilense*, *Chydorus sphaericus*, *Mesocyclops longisetus*, and *Hyalella araucana* (Table 1). Ephemeral shallow mountain ponds (e.g.,

Table 1. Geographical location and species reported for studied sites.
Tabla 1. Localización geográfica y especies registradas en los sitios estudiados.

	Verde II	Marimenuco 1	Marimenuco 2	Puaucho 1	Puaucho 2	Puaucho 3
	Mountain lake	Mountain pool	Mountain pool	Coastal pool	Coastal pool	Coastal pool
	38°40’S, 71°37’W	38º40’S, 71º05’W	38º40’S, 71º05’W	38°57’S, 73°20’W	38°57’S, 73°19’W	38°57’S, 73°19’W
Daphnia pulex	1	0	0	0	0	0
Ceriodaphnia dubia	0	0	0	1	1	1
Scapholeberis exspinifera	0	0	0	0	0	0
Simocephalus serrulatus	0	0	0	0	0	0
Diaphanosoma chilense	0	0	0	0	0	0
Eubosmina hagmanni	0	0	0	0	0	0
Alona guttata	0	0	0	1	0	0
Chydorus sphaericus	0	0	0	0	0	0
Branchinecta	0	0	0	0	0	0
Boeckella gracilis	1	1	1	1	1	1
Mesocyclops longisetus	0	0	0	0	0	0
Ostracoda	0	1	1	1	1	1
Hyalella araucana	0	0	0	0	0	0

	Puaucho 4	Puaucho 5	Puaucho 6	Puaucho 7	Los Patos	Tinquilco
	Coastal pool	Coastal pool	Coastal pool	Coastal pool	Mountain pond	Mountain lake
	38°57’S, 73°19’W	38°57’S, 73°19’W	38°57’S, 73°19’W	38°57’S, 73°19’W	39º10’S, 71º42’W	39°10’S, 71°43’W
Daphnia pulex	0	0	0	0	0	1
Ceriodaphnia dubia	1	1	1	1	0	1
Scapholeberis exspinifera	0	0	0	0	1	0
Simocephalus serrulatus	0	0	0	0	1	0
Diaphanosoma chilense	0	0	0	0	0	0
Eubosmina hagmanni	0	0	0	0	0	1
Alona guttata	0	0	1	0	0	0
Chydorus sphaericus	0	0	0	0	0	0
Branchinecta	0	0	1	1	0	0
Boeckella gracilis	1	1	1	1	1	1
Mesocyclops longisetus	0	1	0	0	1	1
Ostracoda	0	0	0	1	0	0
Hyalella araucana	0	0	0	0	0	0

	De los Patos	Escondida	Seca	Negra	Bella	Los Pastos	Vaca Hundida
	39°15´S, 71°42´W Mountain lake	39°15´S, 71°42´W Mountain lake	39°15´S, 71°42´W Mountain lake	39°15´S, 71°42´W Mountain lake	39°15´S, 71°42´W Mountain lake	39°15´S, 71°42´W Mountain pond	39°15´S, 71°42´W Mountain lake
Daphnia pulex	1	1	1	0	0	0	1
Ceriodaphnia dubia	0	1	1	0	0	1	1
Scapholeberis exspinifera	0	0	0	0	0	0	0
Simocephalus serrulatus	0	0	0	0	0	0	1
Diaphanosoma chilense	1	1	0	0	1	1	0
Eubosmina hagmanni	0	0	0	0	0	0	0
Alona guttata	0	0	0	0	0	0	0
Chydorus sphaericus	0	1	1	0	0	0	0
Branchinecta	0	0	0	0	0	0	1
Boeckella gracilis	1	1	1	1	1	1	0
Mesocyclops longisetus	1	1	1	1	0	1	0
Ostracoda	0	0	0	0	0	0	0
Hyalella araucana	0	0	0	1	0	0	0

Los Patos and Marimenuco) constitute a third type of habitat in which *B. gracilis* coexists with *Mesocyclops longisetus*, *Simocephalus serrulatus*, *Scapholeberis exspinifera*, and *Hyalella araucana* (Table 1) in the first case and with ostracods in the second (Table 1). Finally, the fourth group, ephemeral shallow pools in a sandy dune area (Puaucho Beach), was practically exceptional, with *B. gracilis* coexisting with *C. dubia* and *Chydoridae* (Table 1). The results of the null model analysis for co-occurrence revealed the existence of regulatory factors in two of the three simulations (Table 2). The lack of regulatory factors in the third simulation (fixed-equiprobable) was due to the high incidence of repeated species at many of the studied sites (Table 1).

The present study contributes knowledge about the distribution of this species in continental Chilean territory. Although findings of juvenile copepods that probably belong to *B. gracilis* indicate that this species may be distributed in other mountain lakes and ponds of northern and central Patagonia, it was not possible to confirm the presence of this species in, for example, the lakes of Puyehue and Alerce Andino National Parks (De los Ríos, unpublished data). Given this and the numerous mountain lakes of northern and central Patagonia (Steinhart *et al.*, 2002), it is likely that *B. gracilis* inhabits a wide gradient of mountain lakes between 38° and 42°S, similar to descriptions for Argentinean inland waters (Menu-Marque *et al.*, 2000). One exception was the presence of this species in the shallow ephemeral pools of the Puaucho Beach dunes, although early reports from around Calbuco (Löffler, 1961) and Puerto Montt (Brehm, 1937) indicate that this species may be found in coastal lagoons. The present study helps us understand this species' distribution in Chilean inland waters, but more studies are needed to understand the ecological processes of these habitats.

The null model analysis revealed that the species associations of *B. gracilis* are not random. Rather, regulatory factors exist that explain these associations. Both random and regulatory factors occur in species associations when using fixed-proportional simulation due to the recurrence of a few species at many of the study sites, coinciding with similar results for central and southern Patagonian inland waters (De los Ríos, 2008; De los Ríos *et al.*, 2008a, 2008b; De los Ríos & Soto, 2009). These results agree with theoretical ecological studies based on observations made in terrestrial ecosystems (Ribas & Schoereder, 2002; Tondoh, 2006; Franca & Araujo, 2007; Sanders *et al.*, 2007; Tiho & Johens, 2007). Nevertheless, in spite of the existence of regulatory factors (e.g., trophic status), it was possible to detect random species associations (De los Ríos & Roa, 2010). In this scenario of a potential role of trophic status, dominance by calanoids and a low number of species are associated with oligotrophic water bodies, corresponding to descriptions of many kinds of Patagonian lakes, such as those in Cañi park at 38ºS (De los Ríos & Roa, 2010) and Torres del Paine National Park (De los Ríos & Soto, 2009).

The species assemblages for oligotrophic waters included calanoid copepods and small cladocerans, mainly *Eubosmina hagmanni*, whereas for mesotrophic waters, the calanoids decreased in abundance and coexisted with other cladocerans, mainly of the genera *Daphnia*, *Ceriodaphnia*, and *Chydorus* (De los Ríos & Soto, 2009). These results resemble the observations of the present study (Table 1). Similar results about oligotrophy and its association with a low number of species and elevated levels of calanoid copepods have been reported for Argentinean Patagonian lakes (Modenutti *et al.*, 1998) and New Zealand lakes and ponds (Jeppensen *et al.*, 1997, 2000). Given this information, more ecological studies are necessary because the regulatory factors of the ephemeral pools probably include the combined effects of trophic status and conductivity, specifically in ephemeral coastal (e.g., Puaucho) and mountain (e.g,. Marimenuco) pools, whereas in mountain lakes (e.g., Tinquilco), the trophic status would likely fulfill this role.

Table 2. Results of null model analysis for studied sites. $P < 0.05$ denotes the presence of non-random factors as regulators of species associations.

Tabla 2. Resultados del análisis de modelo nulo para los sitios estudiados. $P < 0.05$ denota la presencia de factores no aleatorios como reguladores de las asociaciones de especies.

	Observed index	Mean index	Standard effect size	*P*
Fixed-Fixed	8.106	7.695	2.241	0.023
Fixed-Proportional	8.106	6.348	2.361	0.005
Fixed-Equiprobable	8.106	7.259	1.377	0.074

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